Watermark Detection Using Adaptive Color Projections

Field of the Invention:

The present invention relates to steganography and more particularly to the detection of watermark in multi-colored images.

Background of the Invention:

Techniques for embedding and detecting watermarks in colored images must take into account that each pixel is defined by a plurality of numbers representing different colors. For example each pixel may have a red, a green and a blue value. Luminance is a single value that can be calculated from the multiple values that define a pixel. A watermark can be embedded in an image by changing the luminance value of the pixels in the image. The luminance of a pixel can be changed by making changes along a particular color axis.

A widely used watermarking embedding technique examines the luminance values in an area surrounding a particular pixel to determine the amount of change in luminance that should be applied to that particular pixel. The watermark is embedded by changing the colors of each pixel along a vector from black to the color of the pixel. This technique can be termed "scale to black" watermark embedding.

A widely used watermark reading technique operates on detected changes in the luminance values of an image. A change in luminance is determined by projecting color changes onto a luminance axis. The change in luminance of each pixel is equal to the change in magnitude of a vector from black to the color of the pixel, projected onto the luminance axis.

Other watermarking embedding and reading techniques select a particular color plane of an image and imbed and read the watermark into and from that color plane.

Some systems that read watermarks apply a non linear filter to the image to obtain a set of values from which the watermark (i.e. the grid signal or the data signals) is read. A non-linear filter can, in effect, calculate a value for each pixel based upon the value of the surrounding pixels. A variety of such non-linear filters have been proposed. Some take into account the value of all adjacent pixels, others take into account the value of the pixels on various axes such as the values on a set of cross axes.

Summary of the Present invention:

The present invention provides a new image filtering technique that matches the color axis of the watermark detector to the color direction used by the watermark embedder. With the present invention, during the watermark reading operation, the changes in the color values of each pixel are not projected onto a luminance axis or onto a particular color axis. With the present invention, a preferred projection axis is determined for each pixel. The preferred projection axis for each pixel approximates the axis used to insert the watermark in that pixel. The preferred projection axis does not necessarily coincide with the luminance axis or with the axis of any other color component of the image. The preferred projection axis for each pixel is determined by examining the color values in an area surrounding that pixel. Once the preferred projection axis for a pixel is determined the color values of that pixel are projected onto this axis to generate a set of values for the pixel. The grid or data signal can then be detected from these values using known techniques in the same way that a watermark can be read from the changes in luminance values of an image.

A second embodiment of the invention inserts two watermarks in an image. The two watermarks are inserted in orthogonal color directions. One of the watermarks can be a fragile watermark. This technique can be used to detect if an image has been duplicated.

Brief Description of the Drawings:

Figure 1 illustrates the pixels in an image.

Figure 2 illustrates the color vectors in a blue image printed with the conventional CYMK colors.

Figure 3 is a block diagram showing the steps in a preferred embodiment.

Figure 4 illustrates use of the invention with two watermarks, one of which is a fragile watermark.

Detailed Description:

Digital color images generally consist of pixels or bits. The color of each pixel is specified by specifying the values for a plurality of colors such as RGB (red green blue), CYMK (cyan yellow magenta and black), etc. Figure 1 illustrates an image that consists of pixels P_{11} to P_{xx}. Each pixel P_{11} to P_{xx} has an associated value for each of the colors (RGB, CYMK, etc).

In order to better appreciate the present invention it is useful to first illustrate how some existing watermark reading programs operate. When reading a watermark some existing watermark reading programs calculate the change in luminance as illustrated in Figure 2 and read the watermark from the calculated luminance changes using a correlation process. Figure 2 illustrates a CYMK (cyan yellow magenta black) image; however, the process is similar for other color representations. The change in luminance of a pixel equals the change in magnitude of a vector from black to the color of the pixel projected onto the luminance axis. Figure 2 illustrates that for a blue pixel a change in the blue color having a magnitude of the vector 201, results in a change in luminance equal to the vector 202. The point which should be noted is that the magnitude of vector 202 (from which the watermark is detected) is smaller than the magnitude of vector 201. If the image were an RGB image, the coordinates would be RGB instead of CYM, but the process and the result would be the same.

In general the present invention is directed to matching the color direction of the detection process to the color direction of the embedding process. This is accomplished by filtering the image in such a manner that the detection process is adaptive to the colors in the image.

The first embodiment of the invention described herein is directed to filtering an image, which has been watermarked by using the "scale to black" watermarking technique. The filtering provided by the present invention makes it easier to read the watermark. Many commercial watermarking programs (such as the watermarking program that is part of the Adobe Photoshop image editing program) embed watermarks using the scale to black technique. In order to watermark an image with the scale to black technique the particular change needed to insert a desired watermark in each pixel is calculated. The watermark is inserted by changing the colors of each pixel by, in effect, modifying a vector from black to the color of the pixel by the particular percentage needed to insert the desired watermark,

By filtering an image using the present invention, the ability to detect and read the watermark using a correlation process is enhanced. In the particular embodiment described herein, the color of each pixel is represented by the colors RGB; however, it should be understood that the invention is equally applicable to images represented by other colors.

Figure 3 shows the operations performed by a first embodiment of the invention. As indicated by block 301, the process begins with a digital image that has been, for example, created by scanning a watermarked physical image. The process is directed to detecting a digital watermark in such a digital image. The digital image consists of a plurality of pixels as indicated in Figure 1. There are three values for

each pixel representing the value of the RGB color components of the color of the pixel.

As indicated by block 303, the "preferred projection axis" for each pixel is first determined as hereinafter explained. A single value for each pixel is next calculated by projecting the three color components of the pixel onto this axis. The calculated single value for each pixel is next compared to the value of the surrounding pixels to determine a projected value as indicated by block 309. Finally as indicated by block 311, correlation is used to detect and read the grid or watermark signal.

The calculation to determine the preferred projection axis will now be explained with respect to pixel P_{45} shown in Figure 1. The value of the color components of pixel P_{45} are designated R_{45} G_{45} B_{45}. First <u>average</u> values (designated aR_{45} aG_{45} aB_{45}) for the RGB colors in the nine pixel area surrounding P_{45} are calculated as follows:

$$aR_{45}\ aG_{45}\ aB_{45} \longrightarrow \sum_1^9 R \quad \sum_1^9 G \quad \sum_1^9 B$$

These values are made into a unit vector by dividing by the square root of the sum of the squares of the values. The resulting unit vector designated r_{45} g_{45} b_{45} is the preferred projection axis for that pixel.

The color values of the pixel P_{45} are next projected onto the preferred projection axis by calculating the dot product of the two vectors as follows:

$$\langle r_{45}\ g_{45}\ b_{45}\rangle \bullet \langle R_{45}\ G_{45}\ B_{45}\rangle$$

The above calculation is done for each pixel in the image. The result is a set of values that can be used to first detect a grid signal. The image would then be scaled and oriented as appropriate and the above calculations would again be made and a watermark data detection algorithm applied. It is noted that the values calculated as described above, could be first be used to detect the grid signal, and

then after the image is oriented, the same values (in a re-oriented location) could be used to detect the watermark data signal.

While the embodiment described above calculated the average values over a nine-pixel area, it is noted that in alternative embodiments the image is calculated over other size areas. For example the average could be calculated over a 100 by 100 pixel area or even over a larger area.

The correlation process to detect and read the grid and watermark data signals does not form a part of the present invention. Various techniques can be used to perform the detection and reading operation. For example, the watermark detection and reading process can be performed by watermark reading techniques described in publicly available literature or by the techniques described in co-pending applications 09/186,962, filed November 5, 1998, or in co-pending application 09/503,881 filed 02/14/2000. The above referenced co-pending applications are hereby incorporated herein by reference.

Figure 2 illustrates, as an example, a pure blue image printed using the conventional CYMK colors. Figure 2 illustrates that when a watermark is embedded by a change in the luminance value reflecting a change in the color blue of a CYMK image, the watermark is predominantly in the yellow color. That is, with a blue image, indicated by the vector 201, a change in luminance indicated by the vector 202 will be primarily be reflected by changes in the yellow color 203.

With the present invention, the detector will automatically look for the watermark primarily in blue color direction as a result of calculating color channel weights as follows.

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red_wt = red_ave / (red_ave + green_ave + blue_ave)
green_wt = green_ave / (red_ave + green_ave + blue_ave)
blue_wt = blue_ave / (red_ave + green_ave + blue_ave)
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In a blue area, red_ave = 0, green_ave = 0, and blue_ave = 255 i.e. red_wt = 0, green_wt =0 and blue_wt = 1. These values are used to weight the red, green and blue pixel values in a pixel block of a selected size (e.g. 3 by 3, 100 by 100, etc.) to create a single weighted average channel, which is used for watermark detection. Thus with the present invention the full blue change is seen by the detector.

The following illustrates what occurs if a watermark detection is done in the luminance channel instead of using the present invention. Luminance is conventionally calculated as follows:

$$\text{Luminance} = 0.3*\text{Red} + 0.6*\text{Green} + 0.1*\text{Blue}$$

With the image illustrated in Figure 2, if detection were done in the luminance channel a much smaller change would be detected. For example a change of 20 in blue would become a luminance change of 2.

It is also noted that by matching the color direction of the detector to the color direction used by the embedder, image noise that would otherwise interfere with the detector is effectively rejected. For example, in the example of a blue image given above any image data in the red and green channels would not interfere with the watermark in the blue channel.

To obtain the maximum benefit from the adaptive color detection, the camera color reproduction should be made as accurate as possible. Standard tools are available for achieving this, such as using ICC color profiles for the camera. For best results, a camera should be individually characterized, or less accurately a generic profile for the camera type can be used. An individual camera is characterized by reading a printed target with known color values. The target values are used to calculate the required color transformation to achieve the expected output values.

The size of the area over which the colors are averaged can range from a 3 by 3 area to an area multiple hundred pixels square. A small area will involve more computation time; however, it will generally provide better results for images that have color areas of smaller size. Watermarking programs generally insert watermarks several times in an image. The size of the area in which the watermark is inserted is sometimes referred to as the tile size. Averaging over an area the size of the watermark tile provides an advantage in that the detector program is configured to operate on pixel areas of this size.

An alternate embodiment of the invention which utilizes two watermarks designated Mark 1 and Mark 2 is illustrated in Figure 4. The second watermark, mark 2, has a lower intensity or strength than the first watermark, Mark 1. The lower strength makes it difficult to copy Mark 2 by scanning or photocopying the image. In order to keep the second watermark, mark 2, from interfering with the first watermark, mark 2 is inserted in a color space orthogonal to the first mark.

Figure 4 illustrates an example of the color directions of the two watermarks. Mark 1 is inserted using a conventional "scale to black" technique. Hence for a blue color this can be represented as a change in the direction of the vector A designated 401. The second watermark is inserted in an orthogonal direction as indicated by the vector 402. In figure 4 the luminance axis is designated as vector B. The direction (designated "V") of the second water mark can be defined as the cross product of vector A and vector B. That is:

$$V = A \wedge B$$

To help distinguish between the two watermarks, the second watermark can also have a different resolution from mark 1. For example mark 1 could be at 75 lpi and mark 2 at 300 lpi.

The first watermark is applied in the same manner as described above relative to the first embodiment. That is, the change needed to embed the first watermark is calculated by in effect scaling by an appropriate amount a vector between black and the color being changed.

The second watermark (i.e. the fragile watermark) is applied, by calculating a color change perpendicular to the direction of the first watermark. The perpendicular color vector (designated V) is calculated by calculating the cross product of vector A and vector B as indicated above. The fragile watermark is applied by scaling the vector V in the same way that the first watermark was applied by scaling a vector from black to the color.

In this example, the detector would first look for watermark 1 in the blue direction, and then for authentication look in the red direction. Mark 2 can have a much smaller payload, since it is only used to verify that mark 1 is valid. Such a scheme would also help diminishes the chances that an attacker can successfully recover the watermark signal from an image and embed it in another image in a manner that enables an accurate decoding of the watermark in the other image. This is the case since the 2 watermarks would be dependent upon the underlying image content. An attack which high pass filters an image and adds this signal to image 2, copies the watermark in a manner which is independent of image content, and would therefore probably fail an authentication step.

While the specific embodiments described herein relate to watermarks in a spatial domain with a particular form of scaling in the color space, the invention can also be used with other watermarking techniques such as those that make changes in the direction of other color vectors in a color space. In such an embodiment, the detector would project to a vector in a direction corresponding to the direction of the embedder.

It is also noted that there are numerous transform domains, including DCT, wavelet, Fourier, Hough, Karhunen Loeve, Haar, Hadamard, Radon, etc. etc. Color specific watermark embedding and detection can be implemented in these transform domains by dividing the image into blocks, transforming the blocks into desired color space (if not already represented in that space), transforming blocks into transform domain, modify transform coefficients according to some embedding function (which may be a linear or non-linear function of the transform coefficients), then inverse transform the modified data to get the watermarked image. Some other approaches make a calculation to get the watermark signal, then inverse transform the watermark signal to the spatial domain, and finally add the spatial domain watermark signal to the original host signal.

In such systems with the present invention the watermark decoder makes a color analysis (on a region by region basis, where the region can be of varying size as previously noted) to determine from which color space to decode the watermark, and then transforms the data to that space, transforms into the transform domain where the watermark signal was embedded, and applies a decode operation compatible with the embed operation (such as correlation, statistical feature calculation, quantization, statistical probability measure, etc.).

While the invention has been shown and described with respect to preferred embodiments of the invention, it should be understood that various changes in form and detail could be made without departing from the spirit and scope of the invention. The invention is limited only by the appended claims and equivalents thereto.

I claim: